Spin filtering in a Quantum Ring with Rashba Coupling

B. Tanatar[1*] and V. Moldoveanu[2]

Abstract- **We study the effect of Rashba spin-orbit coupling on the spin interference in a non-interacting one-dimensional ring connected to two lead theoretically within the non-equilibrium Greens' function formalism. We compute the charge and spin currents and analyze their Aharonov-Bohm oscillations. The geometry of the system is conveniently described by the angle δ between the two leads. We show that for δ=180° (i.e for symmetrically coupled leads) a good filtering of up or down spin orientation is obtained around half-integer multiples of Φ/Φ_0. These particular flux values correspond to degeneracy points for clockwise and counter-clockwise propagating state related to the same spin orientation in the local spin frame of the ring. In contrast, for the asymmetric coupling, i.e., δ=135° the filter efficiency is maximum around integer multiples of Φ/Φ_0. The numerical results suggest that the spin filtering is obtained when the clockwise or counter-clockwise states interfere destructively. The spin filtering regime is stable against variations of the bias applied on the system.**

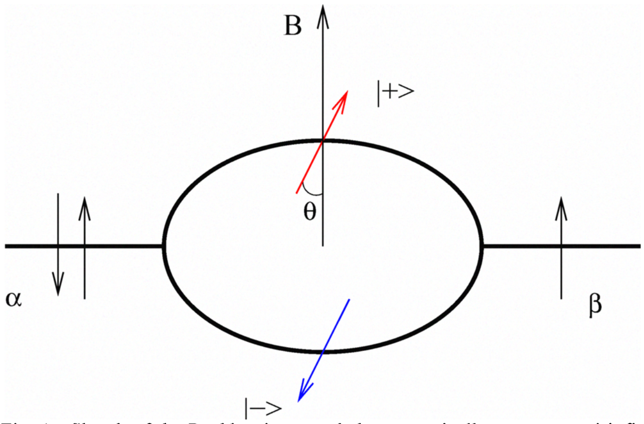

Fig. 1. Sketch of the Rashba ring coupled symmetrically to two semi-infinite leads and subjected to a perpendicular magnetic field. There are two spin representations: on the leads the spin orientatins are given by the up and down spinors, while in the ring we use the spinors with respect to the local spin frame.

I. INTRODUCTION

Nanoscale semiconductor rings are ideal candidates to test quantum coherence effects and the recent field of mesoscopic interferometry focuses on these devices. Traditionally quantum interference in the ring is tuned by the perpendicular magnetic field which results in the celebrated Aharonov-Bohm oscillations in the conductance of open rings and of the persistent currents in the closed rings. [1]

Recently it has been realized that the spin-orbit interaction (SOI) offers an alternative way of observing interference effects in quantum rings.[2],[3] The method is efficient because on one hand the SOI can be controlled by a gate voltage placed in the vicinity of the sample and on the other hand the Rashba SOI strength in confined structures is considerably larger than in vacuum.

The growing interest in mesoscopic rings with tunable interactions is also of importance to spintronics where spin polarized currents are desirable for various applications. It ıs natural then to exploit the tunability of Rashba spin-orbit coupling within the ring to suppress or inhibit currents associated with one spin orientation while allowing the other to escape into the leads. Such a device is called spin filter.

[1]Department of Physics, Bilkent University, Bilkent 06800 Ankara, Turkey

[2]*National Institute of Materials P.O. Box MG-7, Bucharest-Magurele, Romania*

*Contacting Author: email: tanatar@fen.bilkent.edu.tr

The primary goal of our work is to investigate the spin filtering properties of a Rashba interferometer coupled to two leads and subjected to a finite bias. We compute the spin and charge currents and discuss the Aharonov-Bohm oscillations as a function of magnetic field and Rashba coupling strength. We also investigate the filter efficiency for different locations of the contacts to the leads.

II. MODEL AND THEORY

We use the non-equilibrium Green-Keldysh formalism which allows the calculation of steady-state currents in the non-linear regime. We also include the Zeeman coupling which is neglected in other approaches and therefore our results take into account the dependence of the tilt angle on the local spin frame (if the Zeeman coupling is disregarded one has a single tilt angle depending only on the Rashba coupling and

978-1-4244-3544-9/10/$25.00 ©2010 IEEE

on the ring radius).

The calculations are performed by discretizing the Hamiltonian of the continuous ring. By choosing an appropriate number of sites the part of the rings' spectrum that contributes to transport coincides with the same region from the continuous spectrum. Therefore our results are relevant for the continuous systems as well. As in most other approaches to the spin interference in a Rashba ring we do not include the effect of the electron-electron interaction; this approximation seems quite reasonable.[4] However, in the case of rings with embedded or side-coupled dots the intradot Coulomb interaction must be taken into account.

We consider noninteracting electrons moving in a ring of radius R which is subjected to a constant perpendicular magnetic field and also coupled to two one-dimensional leads, as shown in Fig.1. It should be understood that the electrons are forced to move along the ring by a suitable confining potential.

III. Results

In the following we give a representative sample of our numerical results. The spin filter configuration is realized when two leads with different chemical potentials are attached to the ring. We consider the case of two symmetrically attached leads. Fig.2(a) displays the spin currents entering the lead α as a function of the magnetic flux. In the steady-state, current conservation implies which we have numerically verified to hold. We observe the following noteworthy features.

(i) Both spin currents exhibit successive sudden drops which make the spin filtering possible,

(ii) the flux values associated with these drops are always around half integer multiples of flux quantum,

(iii) apart from these regions the two currents are quite comparable and therefore a good spin filtering regime is not to be found at any magnetic field.

A comparison with the spectrum of the system (not shown) reveals that the sharp minima of the spin currents correspond to degeneracy points between the states that travel clockwise and counter-clockwise.

Fig. 3(b) shows the spin-up and spin-down efficiencies for two values of the Rashba coupling strength. As expected from Fig. 3(a) the efficiencies have maxima at the degeneracy points. The increase of Rashba coupling results in larger spacing between the current spikes but also to a reduction of the efficiency.

The above observations suggest that when the filter selects a spin-up (down) the clockwise and counterclockwise waves interfere destructively in the ring and therefore suppress the spin-up (down) current. Our further calculations show that symmetric coupling to the leads is an optimal configuration for spin filtering.

Acknowledgment

This work is supported by TUBITAK (Grant No. 108T743), TUBA,TUBITAK-BIDEP scholarship, and PNCD12 (Grant No. 515/2009).

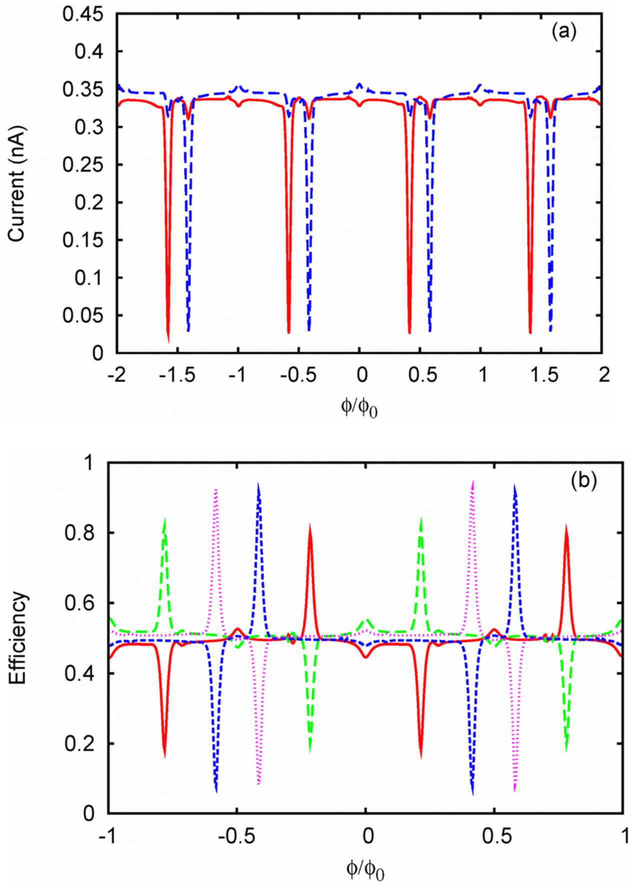

Fig. 2. (a) The spin-up (solid line) and spin—down (dashed line) currents for the 70 nm ring coupled to two leads. (b) Spin filter efficiencies for spin-up (solid line) and spin-down (dashed line) currents.

References

[1] S. Washburn and R.A. Webb, "Aharonov-Bohm effect in normal metal quantum coherence and transport", Adv. Phys. 35, pp. 375-422, 1986.,
[2] M. Kohda, T. Bergsten, and J. Nitta, J. Phys. Soc. Jpn. 77, pp. 31008, (2008).
[3] J. Nitta and T. Bergsten, "Time-reversal Aharonov-Casher effect using Rashba spin-orbit interaction", New J. Phys. 9, pp.341, 2007.
[4] J. Splettstoesser, M. Governale, and U. Zülicke, "Persistent current in ballistic mesoscopic rings with Rashba spin-orbit coupling", Phys. Rev. B 68, pp.165341, 2003.